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NOTES AND COMMENTS

Loss rates of honey bee colonies during winter 2017/18 in 36 countries participating in the COLOSS survey, including effects of forage sources

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This short article presents loss rates of honey bee colonies over winter 2017/18 from 36 countries, including 33 in Europe, from data collected using the standardized COLOSS questionnaire. The 25,363 beekeepers supplying data passing consistency checks in total wintered 544,879 colonies, and reported 26,379 (4.8%, 95% CI 4.7–5.0%) colonies with unsolvable queen problems, 54,525 (10.0%, 95% CI 9.8–10.2%) dead colonies after winter and another 8,220 colonies (1.5%, 95% CI 1.4–1.6%) lost through natural disaster. This gave an overall loss rate of 16.4% (95% CI 16.1–16.6%) of honey bee colonies during winter 2017/18, but this varied greatly from 2.0 to 32.8% between countries. The included map shows relative risks of winter loss at regional level. The analysis using the total data-set confirmed findings from earlier surveys that smaller beekeeping operations with at most 50 colonies suffer significantly higher losses than larger operations ($p < .001$). Beekeepers migrating their colonies had significantly lower losses than those not migrating ($p < .001$), a different finding from previous research. Evaluation of six different forage sources as potential risk factors for colony loss indicated that intensive foraging on any of five of these plant sources (Orchards, Oilseed Rape, Maize, Heather and Autumn Forage Crops) was associated with significantly higher winter losses. This finding requires further study and explanation. A table is included giving detailed results of loss rates and the impact of the tested forage sources for each country and overall.

Keywords: *Apis mellifera*; mortality; forage sources; colony winter losses; monitoring; beekeeping; survey; citizen science

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**Wrote a first draft of the article.
†Did data processing and editing, all statistical analysis, and produced the map.

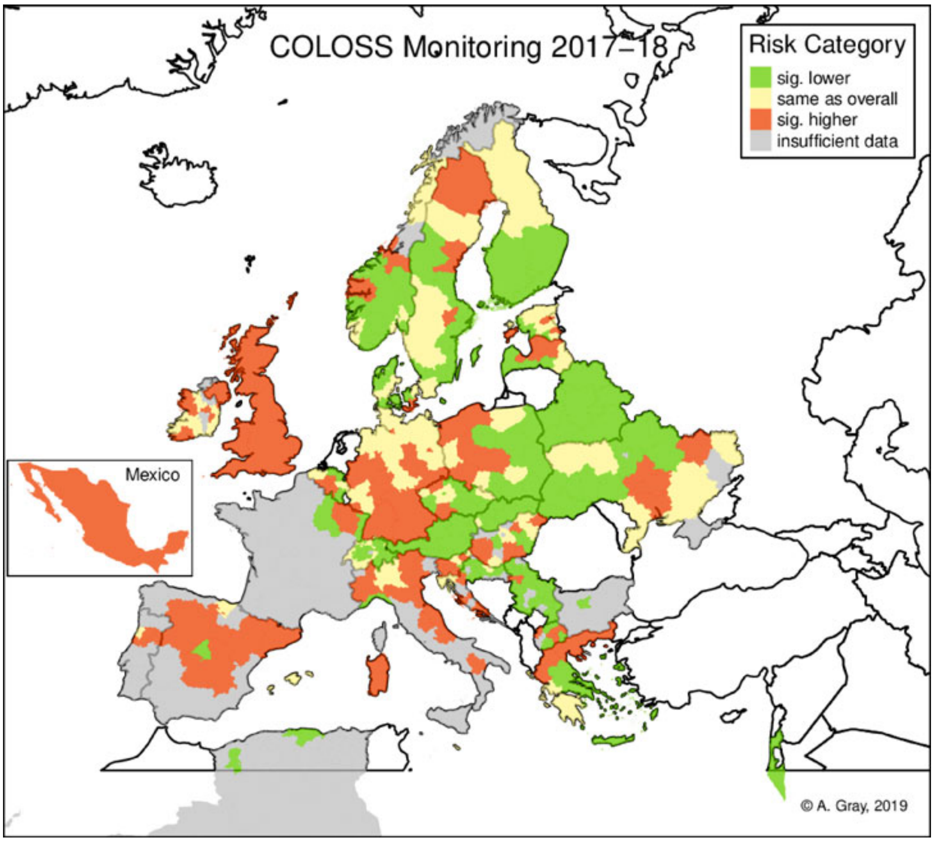

Figure 1. Color-coded map showing relative risk of overwinter colony loss at regional level for participating countries. Notes: Regions with a relative risk of loss (loss rate divided by the loss rate over all regions) that is significantly higher/lower than 1 are shown in red/green respectively. Regions with a relative risk not significantly different from 1 are shown in yellow. Where no data were available or data were available from fewer than 6 beekeepers in a region within a participating country, this was treated as insufficient for reliable calculation and the region is shown in gray. Countries not present in the study are indicated in white (blank areas in the map). Information on region was not available for Mexico, Malta, and Israel; these were each colored at country level. Island groups/regions are colored as one region provided at least six responses were available. The Netherlands is not represented in the map, as the data did not allow calculation of overall loss rate at country or regional level, and hence the relative risk was unavailable.

Monitoring of losses of managed honey bee colonies is a core activity of the non-profit honey bee research association COLOSS. The COLOSS monitoring began in 2008, with a focus on losses over winter, the most important season for colony loss in Europe though not necessarily in all other countries. This ongoing research effort now involves many European and some additional countries, who undertake annual national surveys of beekeepers via a self-administered questionnaire involving standardized questions for comparability of responses (van der Zee et al., 2013). The data collection is organized at national level and takes place in different ways depending on the country, including internet, paper and email surveys and telephone calls.

Here, we present summary results from the COLOSS survey of losses over winter 2017/18, conducted in spring 2018. This is the third report in a series of short communications (Brodschneider et al., 2016, 2018) which together allow comparison of winter colony losses between countries and over time. These COLOSS surveys represent many thousands of beekeepers over a large and expanding number of participating countries. Anonymous answers are optional, to encourage higher response rates. Earlier studies, including van der Zee et al. (2014), examined multiple risk factors for colony loss in multi-country models. In these short reports, we focus each time on a limited set of potential risk factors but examine their significance in each country providing the relevant data. Here we consider the impact of migration, operation size and the relevance of a few specific sources of forage, for winter loss.

As in the 2017 survey (Brodschneider et al., 2018), beekeepers were asked for the number of colonies wintered, and how many of these colonies after winter (a) were alive but had unsolvable queen problems (e.g. a missing queen, laying workers, or a drone-egg laying queen), (b) were dead or reduced to a few hundred bees and (c) were lost through natural disaster (from various possible causes). To estimate the overall proportion of colonies lost, we calculated the sum given by $(a + b + c)$, which was then divided by the number of colonies going into winter. The data files from each country were checked for consistency of loss data as

Table 1. Winter 2017/18 survey results, showing number of respondents with valid loss data, corresponding number of colonies going into winter, honey bee colony mortality, and loss rates (with 95% CIs).

Country	No. of respon-dents	No. of colonies going into winter	% Mortality Rate (95% CI)	% Rate of loss of colonies due to queen problems (95% CI)	% Rate of loss of colonies due to natural disaster (95% CI)	Overall winter loss rate (95% CI)	Estimated % of beekeepers represented	Effect of Orchards	Effect of Oilseed Rape	Effect of Maize	Effect of Sunflower	Effect of Heather	Effect of Autumn Forage Crops
Algeria[a]	116	12,677	5.2 (4.4–6.2)	3.4 (2.8–4.1)	1.2 (0.7–2.2)	9.8 (8.7–11.1)	<1	na	ns	na	na	ns	ns
Austria	1391	28,373	8.6 (8.0–9.3)	3.2 (2.9–3.4)	0.5 (0.3–0.7)	12.2 (11.5–13.0)	5	na	$n < y^{***}$	$n < y^{***}$	$n < y^{***}$	na	ns
Belarus	114	2469	3.2 (2.4–4.4)	3.8 (2.4–5.9)	0.3 (0.1–0.6)	7.3 (5.6–9.6)	na	ns	ns	na*	na	ns	ns
Belgium	482	3725	16.5 (14.5–18.8)	2.3 (1.7–2.9)	0.6 (0.4–1.0)	19.4 (17.2–21.7)	5	$y, n < DK^{**}$	$y, n < DK^{*}$	ns	$n < y^{*}$	ns	$n < y, DK^{***}$
Bulgaria[a,b]	27	4074	0.7 (0.3–1.9)	1.1 (0.4–3.5)	0.2 (0.1–0.7)	2.0 (0.9–4.5)	<1	ns	ns	ns	ns	na	ns
Croatia	209	17,430	10.4 (8.8–12.2)	2.2 (1.8–2.6)	1.2 (0.7–2.0)	13.7 (11.9–15.7)	2	ns	ns	$y < n, DK^{***}$	ns	ns	$n < y, DK^{**}$
Czech Republic	1181	20,567	9.0 (8.1–10.0)	3.2 (2.8–3.6)	0.9 (0.7–1.1)	13.0 (12–14.1)	2	na	ns	ns	ns	na	ns
Denmark	1076	11,524	8.9 (8.1–9.8)	4.5 (4.0–5.0)	0.3 (0.2–0.6)	13.7 (12.7–14.8)	17	ns	ns	ns	$n < DK^{**}$	ns	ns
England	485	2800	20.2 (18.0–22.6)	6.1 (5.1–7.2)	1.9 (1.2–2.9)	28.1 (25.7–30.6)	2	ns	ns	$n, DK < y^{**}$	ns	ns	ns
Estonia	169	5660	8.7 (7.0–10.7)	4.3 (3.6–5.3)	3.3 (2.5–4.3)	16.4 (14.3–18.6)	3	ns	ns	na	na	ns	ns
Finland	352	8780	3.9 (3.1–5.0)	5.9 (5.3–6.6)	0.8 (0.6–1.2)	10.7 (9.6–11.9)	12	ns	$y < n, DK^{***}$	ns	ns	ns	$n < y^{*}$
France[a]	531	16,926	11.0 (9.7–12.5)	4.5 (4.1–5.0)	0.6 (0.4–0.8)	16.1 (14.7–17.7)	1	ns	$n < y^{*}$	$n, DK > y^{**}$	$y < n < DK^{***}$	ns	na*
Germany	10,167	121,296	15.2 (14.8–15.6)	3.1 (2.9–3.2)	0.7 (0.6–0.8)	18.9 (18.5–19.3)	8	$n < y^{**}$	$n < y^{*}$	$n < DK < y^{***}$	$n < y, DK^{**}$	$n, DK < y^{***}$	na
Greece	301	31,187	9.4 (7.9–11.2)	7.5 (6.0–9.4)	1.4 (0.9–2.3)	18.4 (15.9–21.1)	1	na	$DK < n^{*}$	$n, DK < y^{**}$	ns	ns	ns
Hungary	208	17,564	13.4 (10.8–16.5)	4.9 (3.7–6.4)	0.1 (0.0–0.6)	18.4 (15.6–21.6)	1	ns	ns	ns	ns	na	ns
Ireland	348	2958	12.2 (10.5–14.2)	9.2 (7.9–10.6)	1.2 (0.8–1.8)	22.6 (20.3–25.0)	12	na	ns	ns	ns	ns	$n < y^{*}$
Israel	54	26,922	0.5 (0.1–1.9)	5.8 (4.5–7.5)	1.8 (1.0–3.4)	8.2 (6.4–10.4)	11	ns	na	$n < y^{*}$	ns	na	na
Italy[a]	352	12,317	17.2 (15.6–18.9)	8.9 (7.7–10.3)	3.3 (2.5–4.4)	29.4 (27.2–31.7)	<1	na	ns	$y < n, DK^{*}$	ns	ns	na
Latvia	406	12,770	8.7 (7.4–10.1)	6.7 (5.3–8.5)	1.2 (0.9–1.6)	16.6 (14.7–18.7)	9	ns	ns	$y, n < DK^{*}$	$n < DK^{***}$	ns	ns

(*Continued*)

Table 1. (*Continued*).

Macedonia	171	10,918	5.6 (4.7–6.6)	6.2 (5.4–7.1)	1.5 (0.9–2.4)	13.2 (11.4–15.3)	na	ns	ns	ns	ns	ns	ns
Malta	11	287	4.5 (2.0–10.0)	7.7 (3.8–15.0)	1.0 (0.1–12.2)	13.2 (7.5–22.3)	4	insufficient data for tests					
Mexico	164	29,240	5.1 (4.1–6.3)	8.8 (6.9–11.0)	5.7 (4.2–7.6)	19.6 (16.7–22.7)	< 1	no data available on forage					
Netherlands	783	5665	16.3 (14.9–17.8)	na	na	na	9	no data available on forage					
Northern Ireland	106	515	24.1 (19.4–29.5)	5.2 (3.3–8.1)	0.6 (0.3–1.3)	29.9 (25.0–35.3)	11	ns	ns	ns	ns	ns	ns
Norway	727	9102	6.7 (5.7–7.8)	3.5 (3.1–4.0)	1.5 (1.1–2.0)	11.7 (10.5–12.9)	18	ns	ns	ns	ns	n < y**	ns
Poland	307	13,226	10.1 (8.4–12.0)	3.5 (2.9–4.2)	0.6 (0.3–1.0)	14.2 (12.3–16.3)	< 1	n < DK**	ns	n, DK < y***	na	ns	ns
Portugal[a]	58	6896	15.3 (11.7–19.9)	6.1 (3.8–9.9)	11.4 (7.2–17.5)	32.8 (26.6–39.8)	< 1	y < n**	na	na	na	ns	ns
Scotland	345	1852	11.9 (9.8–14.4)	7.9 (6.6–9.5)	3.9 (2.6–5.8)	23.7 (20.9–26.7)	19	ns	y < n**	ns	ns	y < n, DK***	ns
Serbia	224	16,419	5.2 (4.2–6.4)	1.7 (1.2–2.5)	0.6 (0.3–1.2)	7.4 (6.2–9.0)	2	ns	y < n*	ns	ns	ns	ns
Slovakia	420	6499	6.6 (5.3–8.2)	2.8 (2.3–3.4)	0.6 (0.4–1.0)	10.0 (8.6–11.7)	2	ns	y, n < DK***	n < DK*	n < y*	na	n < DK**
Slovenia	397	8825	9.0 (7.9–10.2)	20.3 (17.0–24.1)	0.6 (0.4–1.2)	29.9 (26.6–33.5)	4	ns	na	n, DK < y***	ns	n < y*	ns
Spain[a]	173	19,869	14.4 (12.1–17.1)	9.0 (6.8–11.9)	2.8 (2.0–3.8)	26.2 (22.7–30.1)	< 1	DK < y*	ns	ns	DK < y*	DK < n*	n, DK < y**
Sweden	2260	19,570	9.6 (9.0–10.3)	3.6 (3.3–4.0)	1.7 (1.4–1.9)	14.9 (14.2–15.6)	15	n < y***	ns	y < n, DK***	na	ns	n < y**
Switzerland	1370	18,807	7.9 (7.2–8.7)	5.2 (4.8–5.6)	0.7 (0.5–0.9)	13.8 (12.9–14.7)	8	ns	n < DK*	ns	na	na	na
Ukraine	627	22,621	6.7 (5.8–7.7)	2.1 (1.6–2.7)	2.4 (2.0–3.0)	11.3 (10.0–12.6)	< 1	ns	y < n*	ns	ns	na	ns
Wales	34	214	13.1 (8.9–18.8)	10.7 (5.7–19.3)	2.8 (0.6–12.7)	26.6 (19.4–35.4)	2	ns	ns	ns	ns	ns	ns
Overall[c]	25,363	544,879	10.0 (9.8–10.2)	4.8 (4.7–5.0)	1.5 (1.4–1.6)	16.4 (16.1–16.6)	na	n < y, DK***	n < y, DK***	n < y, DK***	y, n < DK***	n < y, DK***	n < y, DK***

Notes: Mortality and loss rates respectively were calculated as a percentage of colonies wintered which died or were lost due to unresolvable queen problems or to natural disaster. Percentage of beekeepers represented was expressed as the percentage of usable responses per estimated number of beekeepers in each country. Calculation of CIs used the quasi-binomial generalized linear modeling (GzLM) approach in van der Zee et al. (2013), and effects of flow on forage sources (and operation size and migratory beekeeping; see text) were tested using single factor quasi-binomial GzLMs to model probability of loss.

[a]Limited geographical coverage of respondents providing data.

[b]Professional beekeepers only are represented here, with a maximum of 3 apiaries.

[c]Excluding Netherlands.

Significance codes used to represent the *p*-values of tests are as follows: "ns" means non-significant ($p > .05$), "na" means not available (data were not provided at all or insufficient data were available for tests comparing loss rates).

y: Yes; n: No; DK: Don't Know represent different categories of responses.

***$p \leq .001$;

**$.001 < p \leq .01$;

*$.01 < p \leq .05$.

reported in Brodschneider et al. (2018). Responses with insufficient or illogical answers were excluded, but for most countries these were a relatively small part of their data-set. Many of the participating countries now access the survey questionnaire via a common online portal which encodes some of the required data consistency checks, hence improving data quality before the central compilation and further checking of data submitted from all countries prior to analysis.

Thirty-six countries submitted data, compared to 30 and 29 in the previous two surveys in 2017 and 2016 respectively. This is the largest number of countries participating in such a survey so far. Here we report for the first time results on colony losses for Portugal, Greece, and Bulgaria, as well as data from England and Hungary after an absence of some years. The Netherlands submitted data after being absent in the 2017 survey for the first time since the COLOSS monitoring began.

More than 27,000 responses were submitted in total, of which 783 limited responses from the Netherlands unfortunately only allowed calculation of the mortality rate (percentage of wintered colonies which were reported as dead after winter), but a further 25,363 beekeepers provided valid and usable loss data according to the above checks. Of the 544,879 colonies wintered by these 25,363 beekeepers, 26,379 (4.8%) colonies were reported lost due to unsolvable queen problems, 54,525 (10.0%) colonies were reported dead after winter and 8,220 (1.5%) colonies were reported as lost due to natural disaster. The numbers of participating beekeepers and colonies wintered are also the largest represented so far in our surveys. For the countries represented here which are members of the European Union (EU), which may be of interest for evaluation of the impact of EU environmental standards and regulations, again excluding the Netherlands, 21,796 beekeepers provided valid loss data, and, of 395,704 colonies which they wintered, 4.8% of colonies (95% CI 4.7–4.9%) were reported lost due to unsolvable queen problems, 11.9% (95% CI 11.7–12.1%) were reported dead after winter, and 1.2% (95% CI 1.2–1.3%) were reported as lost due to natural disaster, giving an overall loss rate of 17.9% (95% CI 17.6–18.2%). These are similar results as for the overall data-set, though the percentage of dead colonies and the overall loss rate are both slightly higher for the EU countries. For all the countries which are in Europe, apart from the Netherlands, the corresponding results were respectively 25,029 beekeepers with valid loss data, who wintered 476,040 colonies and reported 4.6% (95% CI 4.5–4.7%) lost to queen problems, 11.0% (95% CI 10.8–11.2%) dead after winter, and 1.2% (95% CI 1.2–1.3%) lost due to natural disaster, giving an overall loss rate of 16.8% (95% CI 16.5–17.0%), which are similar results to those for the EU countries.

As we have previously found (Brodschneider et al., 2016, 2018), loss rates vary considerably between countries as well as years. Within countries, differences between regions are also evident. Figure 1 shows a color-coded map of the level of the colony loss rate over winter 2017/18 relative to the loss rate for the same winter over all the regions, in the countries and regions where sufficient data were available. This allows visual identification of countries and regions where the loss rates were relatively high for that winter, compared to the overall loss rate. For example, the UK had relatively high loss rates, as did most of the regions shown for Spain, while for Poland and Germany differences in risk levels can be seen between regions. Unfortunately, for some countries we still have data only from some regions, rather than national data. This situation has improved in Italy and Spain over the years of the COLOSS surveys, though relatively few regions of France, Bulgaria and Portugal are covered at present. Survey conditions in Algeria are difficult, and achieving national coverage is a challenge.

The overall loss rate in winter 2017/18 was highest in Portugal (32.8%), a new country to the survey. Other countries with high losses (above 25%) were Slovenia, Northern Ireland, England, Wales, Italy, and Spain, countries mostly in Western Europe. This pattern is similar to the results for winter 2015/16, but different from the last year. For winter 2016/17 the highest winter loss rates were for Germany, Spain, Mexico, Malta, and Serbia. Bulgaria, another new country to this monitoring study, had the lowest loss rate, of just 2.0%, though based on data from only 27 professional beekeepers. Other low loss rates were found for Belarus, Serbia, Israel, Algeria, and Slovakia (all 10% or lower). A year previously, loss rates were lowest in Norway, Northern Ireland and Algeria, and the year before that in Central Europe. Although most rates of loss from natural disaster were very low, the two highest rates this time were above 5% (Mexico) and 10% (Portugal). Winter losses related to queen problems varied between 1.1% in Bulgaria to 20.3% in Slovenia, whereas for winter 2016/17 the rate of this loss for Slovenia was the lowest among the participating countries.

In the previous two surveys in 2017 and 2016, the overall rates of loss due to queen problems were 5.1 and 4.4%, respectively, and the mortality rates were 14.1 and 7.6%, but in the 2016 survey dead colonies included those lost from natural disaster. The loss rate from natural disaster alone in winter 2016/17 was 1.6%, very similar to the current result of 1.5%. We conclude that the loss rate due to natural disaster is very low, although it does vary between countries (Table 1). Rates of loss due to queen problems appear usually to be about 4–5% overall, and the colony mortality rate is the most variable between years, accounting for the main variation in overall loss rates. There is no clear trend in the overall loss rate, which fluctuates over the years: 16.4% (95% CI 16.1–16.6%) of honey bee colonies during winter 2017/18 (Table 1), 20.9% (95% CI

20.6–21.3%) over winter 2016/17 and 12.0% (95% CI 11.8–12.2%) over winter 2015/16. Even though these loss rates over the years are significantly different, the reasons for those differences remain unclear at present and require further studies.

Examining some potential risk factors for winter loss, by fitting a single factor quasi-binomial generalized linear model (van der Zee et al., 2013), to the overall data-set and identifying significant effects, we confirmed our previous results from Brodschneider et al. (2016, 2018) that beekeeping operations with 50 or fewer colonies (hobbyist beekeepers) experience a significantly higher overall winter loss rate ($p < .001$) than larger scale operations. The very low loss rate cited here for professional beekeepers in Bulgaria appears to be consistent with this finding. Brodschneider et al. (2018) also considered migratory beekeeping, and found a significant effect only in a minority of countries and the direction of the effect of migration on the risk of winter loss varied. In the questionnaire for the survey in spring 2018, beekeepers were asked "Did you migrate any of your colonies at least once for honey production or pollination in 2017?", with possible responses "Yes", "No", and "Don't know". This time, the effect of migration was highly significant overall ($p < .001$) and those beekeepers migrating their colonies had lower losses than those not migrating, and this level of loss in turn was much lower than for those responding "Don't know". As the impact of migration is expected to be dependent on distance as well as the reasons for migration, it would be worthwhile evaluating those factors and thus the role of colony migration on colony survival in a separate but more detailed study.

Since lack of proper forage sources for nutrition can be one of the main risk factors for colony loss (Goulson, Nicholls, Botías, & Rotheray, 2015), we also studied the relative loss rates for beekeepers reporting whether or not their colonies had a significant flow on certain forage sources, namely Orchards, Oilseed Rape, Maize, Sunflower, Heather, and Autumn Forage Crops (intended as melliferous plants growing on land lying fallow). Not all of these forage sources were relevant for every country. The questionnaire responses are self-reported data, and beekeepers may not always be fully aware of all forage sources available to their bees. We found overall that for all these plant sources except Sunflower, beekeepers responding "No" had significantly lower losses than those responding "Yes" or "Don't know". For Sunflower, both those responding "Yes" and "No" had lower loss rates overall than those responding "Don't know". For each of the other forage sources, any effect was only significant for a minority of countries (Table 1). In these cases, for Orchards, the beekeepers responding "No" usually experienced a lower loss rate, with an exception for Portugal. For Oilseed Rape, the nature of the effect varied; for example, for Finland, Scotland, Serbia and Ukraine those responding "Yes" had a lower loss rate than those responding "No", whereas for Austria, France and Germany the outcome was the opposite. The greatest number of significant results was found in the case of Maize, though the direction of the effect also varied, and only for Croatia, France, Italy and Sweden did the beekeepers responding "Yes" have a lower loss rate. For Sunflower, only for France did those responding "Yes" have a lower loss rate. Heather was significant for very few countries, and only for Scotland did those responding "Yes" have a lower loss rate. Autumn Forage Crops were also only significant for a small number of countries, but the beekeepers responding "No" had the lower loss rate.

In considering each of the above forage sources in a single factor model for each country, many statistical tests have been carried out. Hence, at country level some model effects (Table 1) are likely to be significant by chance alone. Therefore in the text we focus on the relatively fewer results of the tests for the overall data-set, each of which is both highly significant and based on a very large sample size. The sizes of the significant forage effects for the overall data-set are relatively small; for example, concerning the question of whether Maize constituted an important forage source, the loss rates were 17.6, 15.0, and 17.2% for the beekeepers responding "Yes", "No", and "Don't know", respectively. Nonetheless, in practice a number of factors, each with a small effect, acting together on honey bee colonies, could have a considerable impact.

In fact, the variable results between countries for impact of foraging sources are not surprising. This is a complex issue. On the one hand these forage plants are considered as potentially useful sources of nutrition for bees, helping to build up the colony, for example, Autumn Forage Crops available when other forage may be scarce, however, by extending the active season, late forage availability may also extend length of the reproduction cycle for *Varroa destructor,* weakening the colony and hence making winter losses more likely. Additionally, agricultural crops are also expected to contain agricultural chemicals that can cause negative effects (at lethal and sub-lethal doses) if honey bees are exposed to them, and this may have affected the results for all forage sources considered here apart from Heather and possibly Autumn Forage Crops (Goulson et al., 2015; Simon-Delso et al., 2014). Management of these crops varies between the countries, affecting honey bee colonies accordingly. Additionally, environmental conditions can vary considerably between countries, and within any one country certain crops may be grown only in some areas within that country, hence confounding crop effects and other unspecified factors relating to regional variation. Combining the data-sets for different countries also means that larger countries with bigger data-sets tend to dominate the results, though the effect of this will depend on effect sizes at country level. In an earlier multi-country study by van der Zee et al. (2014), access reported by the beekeeper to foraging on Maize and Oilseed Rape were both highly significantly associated with the risk of winter loss, though the modeling was confined to beekeepers with at most 50 colonies. In that study, colonies reported not to have access to Oilseed Rape had significantly lower risk of loss compared with those reported to have access, while loss rates of colonies managed by beekeepers responding "Don't know" to this question about access were not significantly different to those of colonies with reported access. For Maize, both the colonies reported as having "No access" and those for which the beekeeper responded "Don't know" had significantly reduced risk of colony loss compared to those with reported access to Maize. These results are similar to our results reported earlier. The presence of Oilseed Rape or Maize, often grown over large areas, might also be indicative of a lack of diversity of forage, which could have detrimental effects on colonies (van der Zee et al., 2014). Given the various possible explanations for the forage effects in the current data-set, the impact of agricultural versus natural forage should remain an important factor for future evaluation, especially in view of the current ban on various uses of widely applied neonicotinoid insecticides by the EU member states (OJEU, 2018).

In conclusion, even though our current loss data are based on over 25,000 beekeepers from 36 countries, we aim in the loss monitoring surveys to obtain higher response numbers at national level, and high-quality data. Obtaining a high response rate is important to avoid bias and to achieve higher precision in loss estimation, but also to enable better dissection of the risk factors. In practice national co-ordinators in some countries have reported difficulty in achieving sufficient co-operation to achieve a large sample size, including in Malta, Mexico, Israel and Serbia. Beekeepers may need more motivation to participate in the survey and to provide full and useful responses. In some other countries efforts should continue to achieve a fuller representation of beekeepers at national level.

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References

Brodschneider, R., Gray, A., Adjlane, N., Ballis, A., Brusbardis, V., Charrière, J.-D., … Danihlík, J. (2018). Multi-country loss rates of honey bee colonies during winter 2016/2017 from the COLOSS survey. *Journal of Apicultural Research*, *57*(3), 452–457. doi:10.1080/00218839.2018.1460911

Brodschneider, R., Gray, A., van der Zee, R., Adjlane, N., Brusbardis, V., Charrière, J.-D., … Woehl, S. (2016). Preliminary analysis of loss rates of honey bee colonies during winter 2015/16 from the COLOSS survey. *Journal of Apicultural Research*, *55*(5), 375–378. doi:10.1080/00218839.2016.1260240

Goulson, D., Nicholls, E., Botías, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, *347*(6229), 1255957. doi:10.1126/science.1255957

OJEU. (2018). Official Journal of the European Union, L 132. 30 May, 2018, 5–44. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2018:132:TOC

Simon-Delso, N., San Martin, G., Bruneau, E., Minsart, L.-A., Mouret, C., & Hautier, L. (2014). Honeybee colony disorder in crop areas: the role of pesticides and viruses. *PLoS One*, *9*(7), e103073. doi:10.1371/journal.pone.0103073

van der Zee, R., Gray, A., Holzmann, C., Pisa, L., Brodschneider, R., Chlebo, R., … Wilkins, S. (2013). Standard survey methods for estimating colony losses and explanatory risk factors in *Apis mellifera*. In V. Dietemann, J.D. Ellis, P. Neumann (Eds.), *The COLOSS BEEBOOK, Volume I: Standard Methods for Apis mellifera Research. Journal of Apicultural Research, 52*(4). doi:10.3896/IBRA.1.52.4.18

van der Zee, R., Brodschneider, R., Brusbardis, V., Charrière, J.-D., Chlebo, R., Coffey, M. F., … Gray, A. (2014). Results of international standardised beekeeper surveys of colony losses for winter 2012-2013: analysis of winter loss rates and mixed effects modelling of risk factors for winter loss. *Journal of Apicultural Research*, *53*(1), 19–34. doi:10.3896/IBRA.1.53.1.02